Training and Research in Oceanic and Atmospheric Processes In Tropical Cyclones (TROPIC)

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LONG-TERM GOALS

The overarching goal of this research is to improve tropical cyclone (TC) forecast accuracy.

OBJECTIVES

Three principle objectives are designed to achieve the long-term goal:

1. Improve observational data quality.

2. Increase the accuracy of upper-ocean thermal structure beneath TCs in coupled model initializations.

3. Evaluate TC intensity forecasts based on modeled and observed values ocean heat content.

APPROACH

The research program was divided into two phases: a field phase and a classroom phase. During the field phase, TROPIC personnel, including midshipmen from the U.S. Naval Academy (undergraduate students), officers from the Naval Postgraduate School (graduate students), and one Coast Guard sailor (Assistant Scientist and ONR-sponsored PI) flew with the USAF 53rd Weather Reconnaissance Squadron (WRS) to collect the data upon which this research is based. In addition to the standard suite of airborne reconnaissance sensors, nearly 500 Airborne eXpendable BathyThermographs (AXBTs) have been deployed (over three years) to extend the data set to the ocean. The field phase was conducted with the 53rd WRS at Keesler Air Force Base from July to August 2011 and from July to September in both 2012 and 2013. The classroom phase began at the U.S. Naval Academy immediately following each field phase and continued through each academic year. During the classroom phase, the midshipmen quality controlled, reviewed, and analyzed the data collected during the field phase to address the objectives of this research.

While TROPIC began as a collaborative effort with the Naval Research Laboratory (NRL), Monterey and the USAF 53rd WRS, an opportunity was leveraged to coordinate the field phase of this program

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with a parallel project undertaken by the Interdepartmental Hurricane Conference (IHC) working group. During the summer of 2011, the IHC working group began a 3-5 year forecast demonstration project in which AXBTs are launched from operational flights into Atlantic Basin TCs, the data are input into coupled air-sea models on a near-real-time basis, and the value added of these AXBTs to the coupled numerical model TC forecast output is evaluated. Operational and logistics support from the 53rd WRS for TROPIC research is substantially enhanced through this partnership, and in return, data from the AXBT drops are quality controlled, formatted, and uploaded to the Global Telecommunication System (GTS) by TROPIC personnel. The data are then available to scientists worldwide, including the Navy Coupled Ocean Atmosphere Mesoscale Prediction System – Tropical Cyclone (COAMPS-TC) and the National Centers for Environmental Prediction (NCEP) Environmental Modeling Center (EMC) conducting research on the Hurricane Weather Research and Forecast System (H-WRF) coupled mesoscale model to support the IHC Working Group.

Key personnel for the program and subject matter experts for each phase during FY2013 include:

1. Leads:

> CDR Elizabeth R. Sanabia PhD, USN, United States Naval Academy, Annapolis, MD (PI)

> Bradford S. Barrett, PhD, United States Naval Academy, Annapolis, MD (Investigator)

> CAPT William J. Schulz PhD, USN, United States Naval Academy, Annapolis, MD (Investigator)

> Peter Black, PhD, Naval Research Laboratory, Monterey, CA

2. Field Phase:

> LtCol Jonathan Talbot, USAF, 53rd WRS, Keesler Air Force Base, Biloxi, MS

> Jeffrey Kerling, Naval Oceanographic Office, Stennis Space Center, Stennis, MS

> Steven Jayne, Woods Hole Oceanographic Institute, Woods Hole, MA

3. Classroom Phase:

> Sue Chen, Naval Research Laboratory, Monterey, CA

> James Cummings, PhD, Naval Research Laboratory, Stennis Space Center, Stennis, MS

WORK COMPLETED (FY2013)

1. 2012-2013 Classroom Phase (August 2012-June 2013): The classroom phase of the 2012 TROPIC program focused on quality control of the 2012 AXBT observations, particularly of TCs Ernesto and Isaac. The 2012-13 classroom phase yielded several key results:

A. Following revisions, the first journal article from this project was accepted for publication, entitled "Real-time upper-ocean temperature observations from aircraft during operational hurricane reconnaissance missions: AXBT Demonstration Project year one results" (manuscript #WAF-D-12-00107). See Results and Publications sections.

B. Relative impacts of the AXBTs (as compared to other sensors) deployed during Hurricane Isaac (2012) on the upper-ocean temperature structure in the HYCOM model (courtesy J. Cummings) were quantified. See Results section.

C. Nearly 300 AXBTs from the 2012 field program were quality controlled. Greatest focus was on the AXBTs from Tropical Storm Ernesto and Hurricane Isaac. Those data are available here: http://www.usna.edu/Users/oceano/sanbia/tropic.htm

D. Four midshipman research projects were completed, including:

1. The upper-ocean thermal structure underneath Hurricane Isaac (MIDN 1/C Leiby)

2. The upper-ocean thermal structure beneath Tropical Storm Ernesto (MIDN 1/C Coffey)

3. The impact of upper-ocean temperature observations on SHIPS tropical cyclone forecasts in Tropical Storm Ernesto and Hurricane Isaac (MIDN 1/C McCann)

4. Variation in upper-ocean thermal structure resulting from equations used in AXBT processing (MIDN 1/C Cox).

2. 2013 Field Phase (July-September 2013): The TROPIC team deployed 89 AXBTs from USAF 53rd WRS WC-130J aircraft during 14 flights: 5 missions into Tropical Storms Dorian, Fernand, and Gabrielle, and 9 training flights. The quality-controlled ocean observations were sent to both the Real-Time Data Handling System (RTDHS) at the Naval Oceanographic Office (NAVO) for assimilation into the NCOM and HYCOM ocean models. The NCOM data are then used in the coupled COAMPS-TC, which while on schedule to be run operationally in 2014, was not run in real time during the 2013 season. Both the JJVV and 1-m data were also sent to POCs at URI (for assimilation in the coupled GFDL) and to NCEP/EMC (for assimilation into H-WRF), and the JJVV data were sent to the National Data Buoy Center (NDBC) for upload to the GTS (for worldwide use). Sensor reliability and data transfer statistics are still being collected.

To meet the TROPIC program goal of improving TC forecast accuracy, data collection during the field phase was structured to develop and then employ the optimal (most efficient and effective) ocean sensing strategy for AXBT deployments during operational TC reconnaissance missions. Continued development of this sensing strategy during the 2013 field phase followed from lessons learned during the 2011 and 2012 field phase and the results from simulations during the 2011 and 2012 classroom phases, leading to the following objectives:

A. Ensure that timely and accurate upper-ocean thermal data from AXBT observations are available in real time for assimilation into Navy ocean and coupled TC forecast models (and other models as feasible).

1. Timeliness: Prior to commencing 2013 flight operations, all TROPIC team members were trained in the proper formulation of JJVV messages and in transmission procedures for the RTDHS. Release authority was not delegated this year, following lessons learned from the 2012 field phase. This change, along with the changes to enhance accuracy, will be assessed in the 2013-14 classroom phase.

2. Accuracy: The four steps taken last year to improve AXBT data quality were continued during the 2013 field phase. The mobile climatology of upper ocean temperatures developed last year from the NAVO Master Oceanographic Observation Data Set was again utilized to produce a mean thermal profile for each drop location onboard the aircraft to provide a basis of comparison during each AXBT deployment. Next, the mobile bathymetry database developed in 2012 was once again employed so that operators onboard the aircraft could more accurately determine ocean depth at each deployment location. Third, a squadron navigation computer was borrowed from the 53rd WRS for the duration of the field phase. The mobile navigation computer and accompanying GPS receiver

enabled the team to more accurately track the flight path and more effectively plan AXBT drop locations during each mission. Finally, multiple data inter-comparison opportunities were coordinated to assess the validity of the AXBT temperature measurements, since the sensors used for the project were several years beyond their Navy-designated shelf lives.

B. Increase the spatial and temporal frequency of AXBT deployments such that data denial studies planned for the 2013 classroom phase can identify the optimal temporal and spatial distribution of the AXBT observations to improve model performance.

   1. Increase the quantity of AXBTs deployed during each flight. In 2011 the standard deployment points included the corners of the alpha pattern and the midpoint of the cross legs. In 2012 and 2013, deployment patterns were constructed to distribute AXBTs as evenly as possible across the region of the flight with particular emphasis at the boundaries of oceanographic features, along the forecast track ahead of the storm, and at the locations of previous drop points (to verify cooling).

   2. Decrease the time between AXBT missions. In 2011 AXBT operations were rarely conducted in consecutive TC reconnaissance flights, which led to gaps in data assimilation cycles. One hypothesis tested during 2012 was that improved temporal continuity of observations would improve sequential ocean and coupled model forecasts, which will improve TC forecast accuracy. Adjoint simulations are planned to quantitatively test this hypothesis.

C. Optimize training flight opportunities to:

   1. Test and evaluate older single-channel, shallow AXBTs to increase available inventory of the limited 99-channel deep models remaining in the Navy inventory.

   2. Observe the warm-core ring in the Gulf of Mexico ahead of potential oncoming tropical systems to improve initial conditions in the ocean and coupled models.

   3. Examine variance in the upper-ocean temperatures in a non-TC environment for comparison with upcoming climatology analysis (see 3D below).

3. 2013-2014 Classroom Phase (August 2013-June 2014): Initial analysis during the 2013 TROPIC classroom phase will be focused on the following research objectives:

A. Conduct final quality control on the 2013 AXBT data set. Complete data inter-comparison studies, identify sources of error, and establish corrective procedures.

B. Quantify and evaluate the impact of AXBT observations on coupled COAMPS-TC forecast accuracy in Tropical Storm Ernesto and Hurricane Isaac. Examine the impact of variations in horizontal, vertical and temporal AXBT observation density on ocean model improvement (with S. Chen and J. Cummings, pending funding; carryover from 2012-2013 research objectives).

C. Extend the 2012-2013 classroom-phase analysis on the impact of AXBT observations on statistical (SHIPS) model forecasts to include the SHIPS-Decay model.

D. Understand where variance in the upper-ocean thermal structure is greatest based on a gridded climatology developed from the NAVO Master Oceanographic Observation Data Set (MOODS) resource (see 2A(2) in the Work Completed section above). Analyzing the variance will highlight regions with changing thermal structures and identify areas where extra observations during TC reconnaissance missions might be helpful in reducing error in the coupled model initialization. This work, combined with the vertical and horizontal sampling

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strategy from prior operational missions within TCs (B above) should outline an efficient and effective ocean sampling strategy to support coupled model ocean initialization.

RESULTS

Several operational and research achievements from the FY2013 TROPIC program are outlined below.

1. Operational results include:

    A. The AXBT observations beneath Atlantic TCs were assimilated in near-real-time into the NCODA, operational NCOM, and global HYCOM for operational TC reconnaissance missions (TS Dorian, Fernand, and Gabrielle).

    B. For the third year in a row, the TROPIC AXBT observations from beneath Atlantic TCs were uploaded to the GTS, frequently in near-real time.

2. Research results to date include the following:

    A. Real-time assimilation of AXBT observations collected beneath Hurricane Isaac reduced the error in the 48-h sea temperature forecast in the HYCOM model more so than any other sensor (Fig. 1, courtesy J. Cummings). This result indicates that these AXBTs observations signifciantly improve the initialization of the upper-ocean thermal structure in Navy ocean models (NCOM and HYCOM). Extension of this error reduction to atmospheric TC track and intensity forecasts is forthcoming.

    B. Without real-time AXBT observations, multiple navy ocean models (NCOM, HYCOM, IASNFS) exhibited both significant error in the location and intensity of major ocean features. For example, data from AXBTs deployed during a loadmaster training flight in the Gulf of Mexico revealed a cold bias in the IASNFS model and an errant representation of a warm core ring by over 200 hundred kilometers in width and over 50 meters in depth. Similar errors were found in both the NCOM and HYCOM analyses prior to assimilating the AXBT observations in the Tropical Storm Emily and Hurricane Irene cases.

    C. Slight improvement was noted to both the coupled COAMPS-TC forecasts of track and intensity during the 2011 field phase (Sanabia et al. 2013). The two TCs analyzed in this study were a weak TS (Emily) and a hurricane immediately prior to and following landfall (Irene). Data denial studies from Tropical Storm Ernesto and Hurricane Irene (which were both observed over water for more than a week) are needed to identify the impact of the TROPIC AXBT observations on the accuracy of TC track and intensity forecasts.
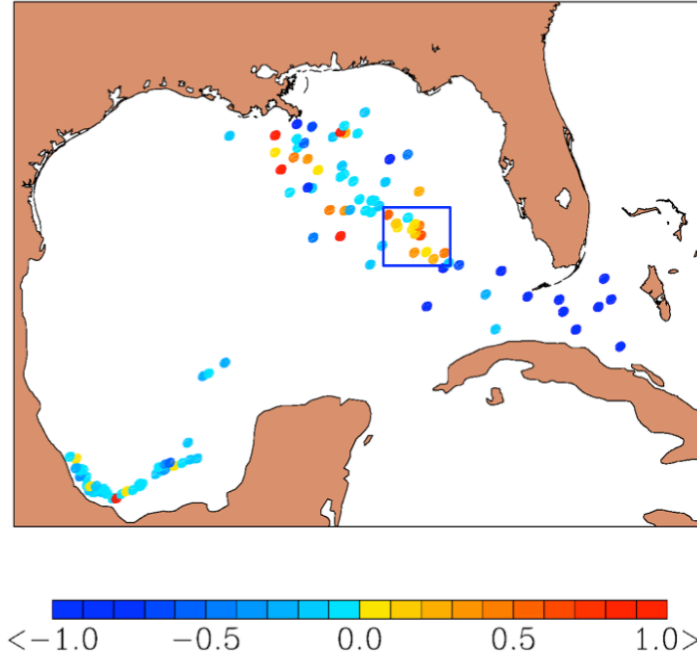
Figure 1. Data map of AXBT impact to HYCOM 48-h sea temperature forecast between 24 August and 04 September 2012. Negative values (cool colors) indicate a beneficial impact (reduction of the 48-h forecast error in deg C). A positive value (warm color) indicates assimilation of the AXBT increased forecast error. The region affected by position reporting errors is outlined in the blue box.
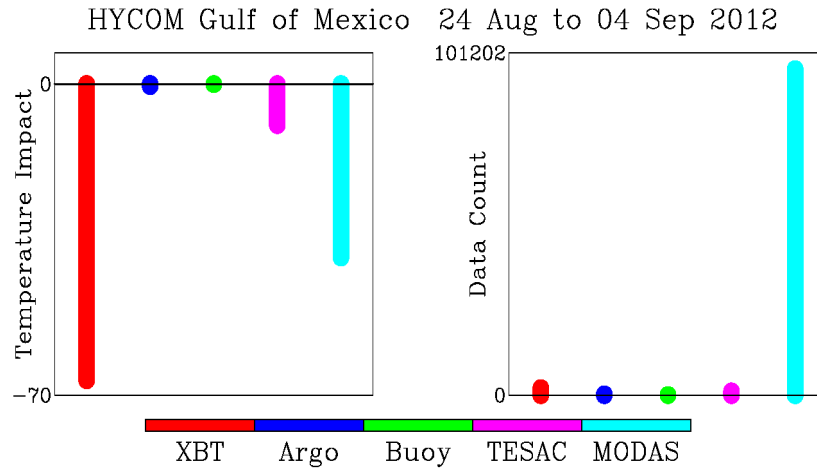

Figure 2. Impact (at left, in degrees C) of each observation type for the analysis in Fig. 1. Number of each observation type is depicted at right.

IMPACT/APPLICATIONS

1. The lessons learned from the TROPIC program will impact AXBT operations through the remainder of the 3-5 year IHC working group forecast demonstration project in several areas:
   A. development and refinement of AXBT systems and procedures, including deployment hardware, data processing software, quality control, and data dissemination.

   B. definition of an ocean sensing strategy to support the optimal spatial and temporal distribution of AXBT observations within and between reconnaissance flights for assimilation into coupled and statistical TC forecast models.

   C. refinement of assimilation schemes and scheduling for coupled TC forecast model runs.

   D. quantfication of the impact of AXBT observations on ocean initialization and TC forecasts.

2. Research may indicate that AXBT data consistently improve TC forecast accuracy. If this is the case, the potential impacts on science and systems include:
   A. The IHC working group may recommend including AXBT operations become standard during airborne hurricane reconnaissance missions onboard the USAF 53rd WRS WC-130J.

   B. The coupled and statistical models including these data may become part of the NHC suite of forecast models.

RELATED PROJECTS

The Naval Research Laboratory, Monterey also receives National Oceanographic Partnership Program funding from the Office of Naval Research and NOAA to improve the performance of coupled mesoscale models (including the coupled COAMPS-TC).

PUBLICATIONS

Sanabia, E. R. , B. S. Barrett, P. G. Black, S. Chen, and J. A. Cummings, 2012: Real-time upper-ocean temperature observations from aircraft during operational hurricane reconnaissance missions: AXBT Demonstration Project year one results. *Wea. Forecasting*. In press.